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AN ANALYSIS OF PEAK WIND SPEED DATA FROM COLLOCATED MECHANICAL AND ULTRASONIC ANEMOMETERS

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1. INTRODUCTION

This study focuses on a comparison of peak wind speeds reported by mechanical and ultrasonic anemometers at Cape Canaveral Air Force Station and Kennedy Space Center (CCAFS/KSC) on the east central coast of Florida and Vandenberg Air Force Base (VAFB) on the central coast of California. The legacy mechanical wind instruments on CCAFS/KSC and VAFB weather towers are being changed from propeller-and-vane (CCAFS/KSC) and cup-and-vane (VAFB) sensors to ultrasonic sensors under the Range Standardization and Automation (RSA) program. The wind tower networks on KSC/CCAFS and VAFB have 41 and 27 towers, respectively. Launch Weather Officers, forecasters, and Range Safety analysts at both locations need to understand the performance of the new wind sensors for a myriad of reasons that include weather warnings, watches, advisories, special ground processing operations, launch pad exposure forecasts, user Launch Commit Criteria (LCC) forecasts and evaluations, and toxic dispersion support.

The Legacy sensors measure wind speed and direction mechanically. The ultrasonic RSA sensors have no moving parts. Ultrasonic sensors were originally developed to measure very light winds (Lewis and Dover 2004). The technology has evolved and now ultrasonic sensors provide reliable wind data over a broad range of wind speeds. However, because ultrasonic sensors respond more quickly than mechanical sensors to rapid fluctuations in speed, characteristic of gusty wind conditions, comparisons of data from the two sensor types have shown differences in the statistics of peak wind speeds (Lewis and Dover 2004). The 45th Weather Squadron (45 WS) and the 30 WS requested the Applied Meteorology Unit (AMU) to compare data from RSA and Legacy sensors to determine if there are significant differences in peak wind speed information from the two systems.

Note that the instruments were sited outdoors under naturally varying conditions and that this comparison was not designed to verify either technology.

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2. DATA AND SENSOR DESCRIPTIONS

Approximately three weeks of mechanical and ultrasonic wind data from KSC/CCAFS and VAFB were recorded during May & June 2005 for use in this study. The CCAFS/KSC data spanned the full diurnal cycle. The VAFB data were confined to 0900-1500 local time.

The sample of 1-minute data from five different towers on each range totaled more than 500,000 minutes of data (482,979 minutes of data after quality control). The ten towers were instrumented at several levels, ranging from 12 ft to 492 ft above ground level. The ultrasonic sensors were collocated at the same vertical levels as the mechanical sensors and typically within 15 ft horizontally of each other. Data from a total of 53 RSA ultrasonic sensors, collocated with mechanical sensors were compared.

2.1 Mechanical Sensors

Figure 1 shows a schematic image of the Legacy propeller-and-vane type wind sensor mounted on the five KSC/CCAFS towers used in this study. The sensor is comprised of a wind vane that aligns itself with the wind direction and a propeller that spins at a rate directly proportional to the wind speed. The wind speed and direction information is output every second and a local data processing system determines the one-minute average conditions and the peak conditions.

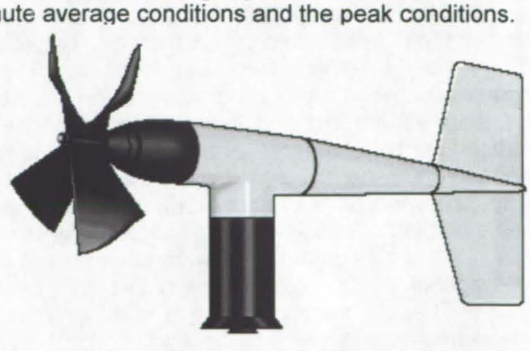

Figure 1. Schematic image of the propeller-and-vane type wind sensor used on the 5 KSC/CCAFS towers (R. M. Young Model 05305 Wind Monitor-AQ; see Computer Sciences Raytheon (2000) for details). Wind speed accuracy is +/- 0.58 kt. The starting threshold wind speed is 0.64 kt.

The five KSC/CCAFS towers used in the present study were among the 33 used by Case and Bauman (2004) for a nine-year climatological study of Legacy wind data from the tower network.

Figure 2 shows the Legacy wind sensor system mounted on the five VAFB towers used in this study. The Model TG1500 by Met One Instruments, Inc., is comprised of a wind vane that aligns itself with the wind direction and a set of cups that spin at a rate directly proportional to the wind speed. The wind speed and direction information is output every second and a local data processing system determines the one-minute average and peak conditions.

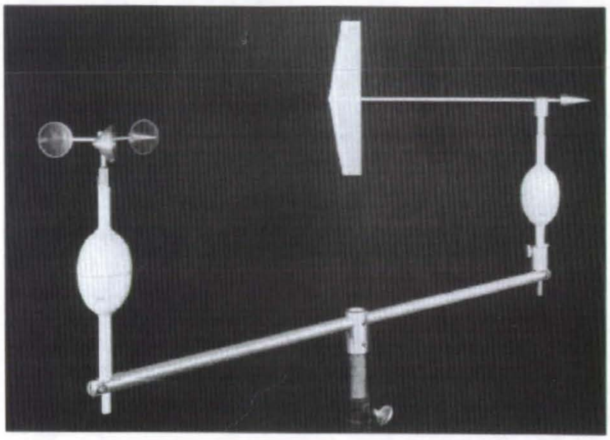

Figure 2. Image of the cup-and-vane type wind sensor mounted on the 5 VAFB towers used in this study (Met One Instruments Model TG1500 Wind Sensor System). Wind speed accuracy is +/- 0.15 kt or 1% of wind speed, whichever is greater. The distance constant is 5 ft.

2.2 Ultrasonic Sensors

Figure 3 shows an image of the Vaisala WS425 Ultrasonic Wind Sensor used in this study. It has three equally spaced ultrasonic transducers mounted in a horizontal plane (Vaisala 2004). The sensor measures the transit time of ultrasonic pulses from one transducer to the other, in both directions. The transit time increases on upwind paths and decreases on downwind paths, the difference being proportional to the wind speed component along the path. Estimates of the wind components on the three paths are derived from 32 upwind-downwind pairs along each path. The 96 pairs are obtained in about 0.2 sec. A proprietary algorithm is then used to quality-control the raw data and to produce a wind speed/direction reading every second from the 96 pairs. These 1-second data are used to produce 1-minute mean and peak wind speed/direction readings each minute.

Figure 3. Image of the ultrasonic type RSA wind sensor mounted on the 10 towers used in this study (Vaisala Model WS425 Ultrasonic Wind Sensor). See Vaisala (2004) for details. Wind speed accuracy is +/- 0.26 kt or 3% of wind speed, whichever is greater. The starting threshold is virtually zero.

3. ANALYSIS PROCEDURE

The analysis procedures were designed to compare Legacy and RSA sensor readings at the highest temporal resolution available and to avoid wind sheltering effects by the tower. Detailed comparisons of 1-minute average wind speed and direction were used to identify the most consistent collocated RSA/Legacy sensor pairs. The consistency tests were performed due to the uncontrolled nature of this comparison. That is, the sensors were simultaneously exposed to the ambient winds with no *a priori* hypothesis as to which sensor was correct. The most consistent pairs, based on difference and rms statistics of average wind speed and direction, were then used to produce the peak wind speed comparisons.

3.1 Matched Time Series

Wind speed data for each RSA/Legacy sensor pair were matched, minute-by-minute, in time series mode. If data from either sensor were missing, that minute was excluded from the analysis.

3.2 Wind Sector Filters

The Legacy wind direction at each level on each tower was used to separate the matched time series into sectors. The sectors were upwind of the tower for each of the possible sensor comparisons. This was done to avoid sheltering effects downwind of the towers.

For example, the VAFB towers had two RSA sensors and one Legacy sensor at each level. The RSA sensors were on diagonally opposite corners of the square towers, while the Legacy sensor was on one of the other corners. This configuration led to three sectors for sensor comparisons.

The data from KSC/CCAFS was from one RSA sensor on each tower and one or two Legacy sensors, depending on the tower. The comparisons in these cases were always between the RSA sensor and the nearest Legacy sensor.

3.3 *Statistical Methods*

The matched time series of average wind speed and average wind direction were used to compute difference and rms statistics for each RSA/Legacy sensor pair from the minute-by-minute data, after the wind direction filters were applied. These provided measures of consistency that were used to identify the most consistent pairs.

In addition, a conditional analysis of average wind speed was made. For example, for a given Legacy sensor and all of its average wind speeds of 1-knot, the corresponding average RSA wind speed from the collocated sensor was calculated. This procedure was carried out for all sensor pairs, after the wind direction filters were applied, over the full range of resulting wind speeds.

4. RESULTS

The results of the sensor comparison are presented in this section in three different ways:

- Overall average wind speeds and peak wind speeds for all sensors,
- Difference and rms statistics of average wind speed and direction, and
- Overall conditional analyses of peak wind speed from the most consistent sensor pairs.

4.1 *Overall Peak Wind Speed Comparison*

The result for all collocated sensor pairs, after filtering for wind direction, gave the follow overall comparison of averaged peak wind speeds:

- Mechanical 10.72 kt
- Ultrasonic 11.78 kt

4.2 *Difference and rms statistics*

An examination of minute-by-minute differences in average wind speed and average wind direction showed that some sensor pairs were more consistent than others. Subjective criteria were used to separate the sensor pairs into the least and most consistent pairs. The RSA difference and rms statistics of wind speed and wind direction were as follows:

Most consistent (33 sensor pairs):

- Average wind speed difference 0.31 kt; rms 0.88 kt
- Average wind direction difference 0.59°; rms 5.40°

Least consistent (20 sensor pairs):

- Average wind speed difference -0.24 kt; rms 1.61 kt
- Average wind direction difference -3.52°, rms 15.81°

4.4 *Overall Peak Wind Speed Comparison for most consistent pairs*

The result for the most consistent sensor pairs, after filtering for wind direction, gave the following overall comparison of averaged peak wind speeds:

- Mechanical 10.95 kt
- Ultrasonic 11.93 kt

The difference of 0.98 kt in the averaged peak wind speeds is significant due to the large sample size and small standard deviation of differences in the minute-by-minute data, +/- 1.10 kt. The sample size of 259,620 gives a highly significant Student-t statistic of 454.

4.5 *Conditional analysis of peak wind speed data*

After separating the sensor pairs into the most and least consistent groups, the peak wind speed data for the most consistent pairs was subjected to the conditional analysis described in Section 3.3. The results for the most consistent sensor pairs on VAFB and KSC/CCAFS are shown in Figure 4.

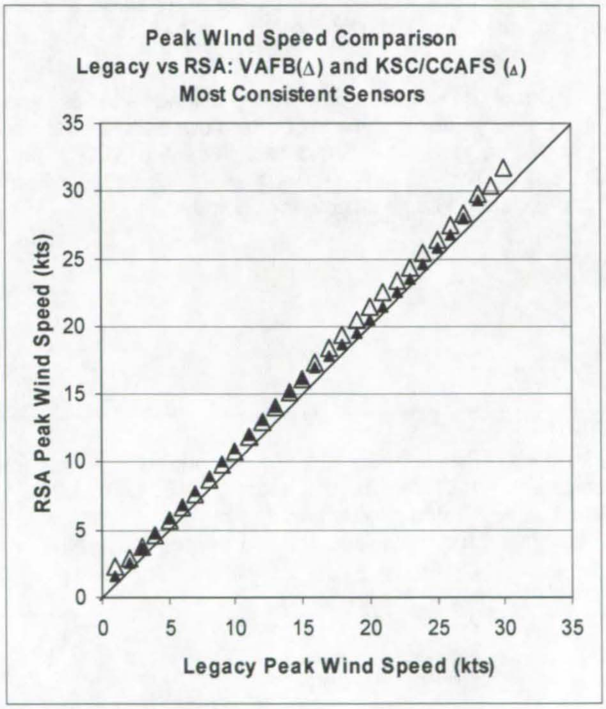

Figure 4. Comparison of peak wind speed data from most consistent Legacy (mechanical) and RSA (ultrasonic) sensor pairs at VAFB (open triangles) and KSC/CCAFS (closed triangles). The square of the correlation coefficient exceeds 0.999 at both locations.

Overall, the ultrasonic and mechanic sensors match closely. However, figure 4 shows a tendency for the difference between the RSA ultrasonic and Legacy peak wind speeds to increase with increasing wind speed. The tendency can be approximately expressed as a +7% RSA difference in peak wind speeds.

5. DISCUSSION

From an operational point of view, the differences in peak wind speeds found in this study are important, indicating that changing from mechanical to ultrasonic sensors will likely result in an increase in reported peak wind speeds. Such an increase in peak wind speeds may result in a decrease of launch availability, depending on the LCC wind speed threshold. Since a launch scrub costs hundreds of thousands to over a million dollars, depending on the launch vehicle, a change in launch opportunity of only a few percent can be costly.

A recent study by Yahaya and Frangi (2004) noted higher variances in ultrasonic wind speeds by about 10%, compared to mechanical, when sampled at 1 and 2 Hz. The observed differences in peak wind speeds found in the present study can be approximated by a Monte Carlo process in which a simulated mechanical system has a smaller variance in 1-second wind speeds than the simulated ultrasonic system, by about 10%. The effective difference in variance may be due to an effective temporal smoothing by the mechanical system or a greater sensitivity of the ultrasonic system to small scale turbulence.

Small differences in average wind speeds and some anomalous behavior of one ultrasonic sensor are reported in detail by Short and Wheeler (2006a and 2006b). The final reports are available at http://science.ksc.nasa.gov/amu/home.html.

6. REFERENCES

Case, J, L., and W. H. Bauman, III, 2004: Tower Mesonetwork Climatology and Interactive Display Tool. NASA Contractor Report CR-2004-211526, Kennedy Space Center, FL, 88 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 230, Cocoa Beach, FL, 32931].

Computer Sciences Raytheon (CSR), 2000: 45th Space Wing Eastern Range Instrumentation Handbook, Computer Sciences Raytheon, Inc., 758 pp.

Lewis, R., and J. M. Dover, 2004: Field and Operational Tests of a Sonic Anemometer for the Automated Observing System. AMS Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface. Seattle, WA, 12-16 January 2004. Paper 7.1, 6 pp.

Short, D.A., and M. W. Wheeler, 2006a: RSA/Legacy Wind Sensor Comparison: Part I: Western Range. NASA Contractor Report CR-2006-214200, Kennedy Space Center, FL, 23 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 230, Cocoa Beach, FL, 32931].

Short, D.A., and M. W. Wheeler, 2006b. RSA/Legacy Wind Sensor Comparison: Part II: Eastern Range. NASA Contractor Report CR-2006-214205, Kennedy Space Center, FL, 23 pp. [Available from ENSCO, Inc., 1980 N. Atlantic Ave., Suite 230, Cocoa Beach, FL, 32931].

Vaisala, 2004: Ultrasonic Wind Sensors WS425 User's Guide. Vaisala Oyj, Helsinki, Finland, 95 pp.

Yahaya, S., and J. P. Frangi, 2004: Cup anemometer responses to the wind turbulence - measurement of the horizontal wind variance. *Annales Geophysicae*, **22**, 3363-3374.